Surface Wave Dynamics in the Coastal Zone

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LONG-TERM GOALS

The proposed work will contribute to the improvement of existing third-generation (3G) wave models as well as to the development of the next generation of numerical wave modeling capability. The results will be applicable in the coastal zone from deep water up to and including the surf zone. Our efforts will focus on analyzing high quality datasets to support further development of the source terms for triad interactions (Snl3), depth induced wave breaking (Sbrk) and bottom friction (Sbot) in the near-shore zone. Another point of interest is the generation of bounded long waves in the surf zone.

OBJECTIVES

The scientific or technological objectives of this project are to understand the physical processes of the evolution of wind waves in the coastal zone and develop accurate parameterisations of these processes for application in numerical wave prediction models.

APPROACH

The proposed work is subdivided in five main work packages (WP).

1) Assembly of high quality data set;
2) Analysis of spectral evolution;
3) Development of a source term for wave breaking in shallow water;

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4) Development of a source term for triad interactions.
5) Improvement of source terms for bottom friction.

WORK COMPLETED

Collection of data sets

TU Delft and BMT Argoss extended their collection of shallow water wave data suitable for the calibration and verification of newly developed source terms for wave breaking, bottom friction and triad interactions. This set comprises wave flume and field data. An overview of the most relevant data set collected is given in the previous annual report. Full details are provided in the manuscripts prepared by Salmon and Holthuijsen (2013, and Salmon et al. (2013).

Development of source term for wave breaking

An study of the literature on depth-induced wave breaking was carried out resulting in a comparison of 12 different parameterizations using 4 different dissipation models (and versions thereof) summarized in Figure 1.

Scatter index	#	BJ'78				TG'83					Bald'98		DDD'85
		0.73	Mad'76	Ting'01+	T&M'02	S&Hol'85	S&How'89	Lipp'96+	vdW'09	FA'12	Rue'03	J&B'07	R&S'03/07
Slopes													
Wallingford*	49	0.06	0.10	0.11	0.18	0.08	0.13	0.16	0.07	0.06	0.07	0.08	0.06
Katsardi*	18	0.13	0.14	0.23	0.34	0.16	0.22	0.24	0.15	0.10	0.16	0.17	0.12
Smith*	31	0.08	0.08	0.13	0.26	0.14	0.22	0.28	0.08	0.11	0.10	0.10	0.09
Boers*	3	0.05	0.07	0.15	0.41	0.19	0.31	0.36	0.06	0.13	0.11	0.08	0.10
B-J*	2	0.05	0.13	0.15	0.34	0.13	0.24	0.32	0.06	0.07	0.07	0.07	0.10
Petten**	8	0.15	0.17	0.19	0.57	0.45	0.53	0.55	0.15	0.23	0.15	0.13	0.15
Horizontal													
Wallingford*	49	0.07	0.07	0.10	0.29	0.11	0.13	0.13	0.08	0.07	0.07	0.07	0.06
Katsardi*	5	0.10	0.10	0.11	0.40	0.19	0.26	0.27	0.10	0.03	0.11	0.11	0.10
Jensen*	45	0.21	0.21	0.37	0.30	0.11	0.14	0.14	0.27	0.21	0.24	0.26	0.26
AZG**	3	0.16	0.15	0.10	0.58	0.47	0.53	0.55	0.10	0.24	0.15	0.14	0.20
Lakes**	5	0.16	0.17	0.08	0.64	0.66	0.71	0.71	0.10	0.27	0.02	0.02	0.11
Guam**	4	0.38	0.29	0.52	0.79	0.41	0.45	0.48	0.56	0.47	0.39	0.29	0.44
Haringvliet**	3	0.16	0.16	0.35	0.51	0.32	0.56	0.60	0.19	0.11	0.20	0.21	0.13
Averages													
slopes	111	0.09	0.12	0.16	0.35	0.19	0.27	0.32	0.10	0.12	0.11	0.10	0.10
horizontal	114	0.18	0.16	0.23	0.50	0.32	0.40	0.41	0.20	0.20	0.17	0.16	0.18
laboratory*	202	0.09	0.11	0.17	0.32	0.14	0.20	0.24	0.11	0.10	0.12	0.12	0.11
field**	23	0.20	0.19	0.25	0.62	0.46	0.55	0.58	0.22	0.27	0.18	0.16	0.20
overall	225	0.13	0.14	0.20	0.43	0.26	0.33	0.37	0.15	0.16	0.14	0.13	0.14
		s.i.< 0.10		0.10<s.i.<0.20		0.20<s.i.<0.40		s.i.>0.40				# 1-7	# 8-12

BJ'78 = Battjes & Janssen [1978]
TG'83 = Thornton & Guza [1983]
Bald'98 = Baldock et al. [1998]
DDD'85 = Dally et al. [1985]
J&B'07 = Janssen & Battjes [2007]

0.73 = fixed in third-generation models
Mad'76 = Madsen [1976]
Ting'01+ = Ting [2001, present authors]
T&M'02 = Tajima & Madsen [2002]
S&Hol'85 = Sallenger & Holman [1985]
S&How'89 = Sallenger & Howd [1989]

Lipp'96+ = Lippmann et al. [1996, present authors]
FA'12 = Filipot & Ardhuin [2012]
vdW'09 = van der Westhuysen [2009]
Rue'03 = Ruessink et al. [2003]
R&S'03/07 = Rattanapitikon et al. [2003] + Rattanapitikon [2007]

Figure 1. Scatter index of the 12 models based on 13 data sets containing 225 cases of laboratory observations (*) and field observations (**). The highlight colors indicate the two ranges of performance (green and blank) and four ranges of scatter index (from blank to orange).

The main conclusion of this comparison, in agreement with previous studies e.g. Apotsos et al. [2008], is that no one model with default settings provided the best predictions for significant wave height.

Furthermore, even the simplest models e.g. Battjes and Janssen [1978] and Rattanapitikon [2007] performed, on average, similarly to more recent and complex parameterizations e.g. Filipot and Ardhuin [2012].

This disappointing conclusion led to the $\beta - kd$ scaling for the Battjes and Janssen dissipation model (Fig. 2) which provides a joint dependency on both local slope and local water depth normalised by wave length. This new scaling was shown to resolve the problem of overestimating wave heights in horizontal laboratory cases e.g. Jensen [2002] and underestimating wave heights in (1-D idealized) cases of locally generated waves e.g. Young and Babanin [2006] and Bottema and van Vledder [2009]. However, the performance of the $\beta - kd$ over the field cases showed no significant improvement, and in fact a reduction, in the skill of predicting significant wave heights (Fig. 3).

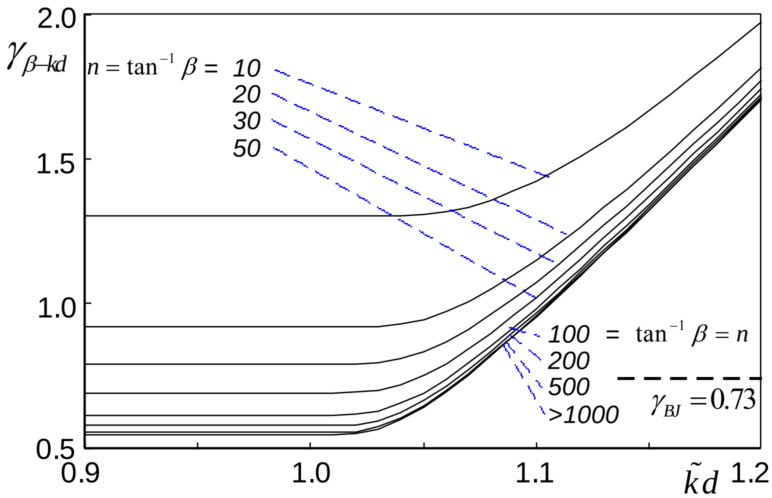

Figure 2. Calibrated $\gamma_{\beta-kd}$ as a function of bottom slope $n = \tan^{-1}\beta$ and normalized wave number $\tilde{k}d$ and $\gamma_{BJ} = 0.73$ for reference.

Scatter index	#		$\beta - kd$					
		$\gamma_{BJ} = 0.73$	no correction	$\sigma_\theta^* = 30^o$	$\sigma_\theta^* = 25^o$	$\sigma_\theta^* = 20^o$	$\sigma_\theta^* = 15^o$	$\sigma_\theta^* = 10^o$
Slopes								
Wallingford*	25	0.08	0.11	0.11	0.11	0.11	0.11	0.11
Katsardi*	7	0.14	0.12	0.12	0.12	0.12	0.12	0.12
Smith*	31	0.08	0.07	0.07	0.07	0.07	0.07	0.07
Boers*	3	0.05	0.07	0.07	0.07	0.07	0.07	0.07
B-J*	2	0.05	0.10	0.10	0.10	0.10	0.10	0.10
Petten**	8	0.15	0.21	0.21	0.20	0.18	0.16	0.18
Horizontal								
Wallingford*	25	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Katsardi*	5	0.10	0.05	0.05	0.05	0.05	0.05	0.05
Jensen*	25	0.21	0.08	0.08	0.08	0.08	0.08	0.08
AZG**	3	0.16	0.23	0.20	0.17	0.12	0.08	0.08
Guam**	4	0.38	0.32	0.31	0.30	0.29	0.28	0.27
Haringvliet**	3	0.16	0.16	0.17	0.16	0.12	0.12	0.23
Lakes	*5*	*0.16*	*0.02*	*0.02*	*0.02*	*0.03*	*0.05*	*0.07*
Averages								
slopes	76	0.09	0.11	0.11	0.11	0.11	0.11	0.11
horizontal	65	0.18	0.15	0.15	0.14	0.13	0.12	0.13
laboratory*	123	0.10	0.09	0.09	0.09	0.09	0.09	0.09
field**	18	0.21	0.23	0.22	0.21	0.18	0.16	0.19
overall	141	0.14	0.13	0.13	0.13	0.12	0.11	0.12

s.i.< 0.10	0.10<s.i.<0.20	0.20<s.i.<0.40

Figure 3. Scatter index for the verification of the $\beta - kd$ scaling, with or without directional partitioning for $\sigma_\theta^* = 10^0, 15°, 20^0, 25°$ and 30^0 (results with a fixed scaling $\gamma_{BJ} = 0.73$ as reference only). Performance over laboratory observations (*) and field observations (**) are highlighted in three ranges of scatter index (from blank to dark gray). The Lakes data set (used in the calibration) is not included in computing the average values but are shown to demonstrate the effect due to directional spreading for this data set. Laboratory cases with their long-crested waves are unaffected by directional partitioning and are shown with a cross-hatched background where directional partitioning is used.

It was speculated that for field cases, the analogy of Battjes and Janssen [1978] of a 1-D bore should not necessarily hold true, particularly for short-crested seas topographically induced e.g. by a submerged shoal and that by partitioning the wave field using a characteristic directional width, the dissipation due to depth-induced breaking could be better represented. This effect was added heuristically in the forms of Eq. 1 and 2:

$$\varepsilon_{BJ}^{\theta} = -K_\theta \frac{\alpha_{BJ}}{4} \rho g \bar{f} Q_b H_{\max}^2 \tag{1}$$

where

$$\frac{1 - Q_b}{\ln Q_b} = -\left(\frac{H_{rms} \sqrt{K_\theta^{-1}}}{H_{\max}} \right)^2 \tag{2}$$

With the number of wave partitions estimated with $K_\theta = \sigma_\theta / \sigma_\theta^* \geq 1$ where σ_θ^* represents a characteristic directional width over which the 1-D bore analogy can be assumed to be appropriate. The use of this directional partitioning ($\sigma_\theta^* = 15°$) with the $\beta - kd$ scaling has been shown to significantly improve the prediction for significant wave height in horizontal field cases (see Fig. 3). Currently the effect of adding wave directionality to the 2 best performing models for field cases (Battjes & Janssen [1978] with $\gamma_{BJ} = 0.73$ and Baldock et al. [1998] corrected by Janssen and Battjes [2007] and Alsina and Baldock [2007] with the scaling of Ruessink et al. [2003]; see Fig. 1) is being investigated. Preliminary results show that these 2 parameterizations and the $\beta - kd$ scaling can yield on average similar or better results in the field cases considered if $15° \leq \sigma_\theta^* \leq 20°$. However, the $\beta - kd$ scaling still on average performs best.

Development of source term for shallow water triad wave-wave interactions

An inconsistency was identified for the implementation of the LTA and DCTA models in SWAN arising from the extension to 2D spectra of 1D source terms i.e. $S_{nl3}(f)$ to $S_{nl3}(f,\theta)$ (required for wave models dealing with 2-D energy/action densities) due to the incorrect assumption:

$$\int E(f_1,\theta)d\theta \times \int E(f_2,\theta)d\theta = \int E(f_1,\theta)E(f_2,\theta)d\theta \quad (3)$$

This appears to have led to the default calibration parameter for the LTA model to have been set at a low value of 0.05 (historically 0.5 and 0.1) when Eldeberky [1996] suggests a value of O(1). To avoid an integral over all directions per frequency and directional bins, which would substantially increase computational costs, for 1-D laboratory cases where all the energy are located in only a few directional bins, the source term for the 2-D spectrum for the LTA source term (sum contribution) can be approximated as:

$$S_{nl3}^{+}(f,\theta) \approx \alpha_{LTA}\chi\left[\int E\left(\frac{f}{2},\theta\right)d\theta \times \left[E\left(\frac{f}{2},\theta\right) - E(f,\theta)\right] - \int E(f,\theta)d\theta \times E\left(\frac{f}{2},\theta\right)\right] \quad (4)$$

where α_{EB} represents a calibration parameter of O(1) and χ represents the remaining terms of the original expression of Eldeberky [1996] (his Eq. 7.25). A similar approach was used in the implementation for the source terms for the SPB (Becq-Girard et al., 1999), Toledo and Agnon [2012] and DCTA model (in energy conservative form) (Booij et al., 2009). These implemented source terms were then calibrated over a number of laboratory cases resulting in new calibration parameters of 0.65, 0.75, 0.35 and 0.50 for the LTA, SPB, energy conservative DCTA and Toledo and Agnon models respectively. In addition, the original coefficients given by Becq et al. were re-assessed by setting $\alpha_{SPB} = 1$. The models were then verified against more laboratory observations (Fig. 4).

As shown in Fig. 4, by using bulk parameters alone, it is not possible to select a better model between the calibrated LTA, DCTA and SPB models. However both the DCTA and SPB models appear to give better spectral shapes than the LTA. Current work is now focused on using a performance indicator based on the transfer of energy from the primary peak to the higher harmonics based on the approach of Becq et al. [1999] to select the best model to further develop.

Model	LTA_0	LTA	SPB[1]	$DCTA_E$	SPB[2]
Beji-Battjes	0.18	0.18	0.20	0.18	0.21
Boers	0.15	0.14	0.29	0.11	0.14
LOWISH	0.09	0.10	0.07	0.09	0.07
Smith	0.10	0.10	0.11	0.11	0.12
Wallingford	0.09	0.08	0.10	0.11	0.08
Average	0.12	0.12	0.15	0.12	0.12

Figure 4. Average scatter indices of H_{m0} and $T_{m0,2}$ from the verification over laboratory observations of the new calibration parameters. The current default for SWAN, LTA_0, is added for reference The model of Toledo and Agnon are not included due to its undeveloped state and poor performance in shallow water ($kd < 1$) (e.g. Fig. 5).
[1]Represents the SPB model with $\alpha_{SPB} = 0.75$ and $K = 0.95k_p - 0.75$ i.e. using the coefficients suggested by Becq et al. and calibrating.
[2]Represents the SPB model with $\alpha_{SPB} = 1.00$ and $K = 0.70k_p - 0.10$ i.e. re-calibrating he coefficients of Becq et al. (1999).

Future work will involve verifying an improved LTA, DCTA or SPB model for applicability with third-generation wave models in field conditions and reducing the computational effort required.

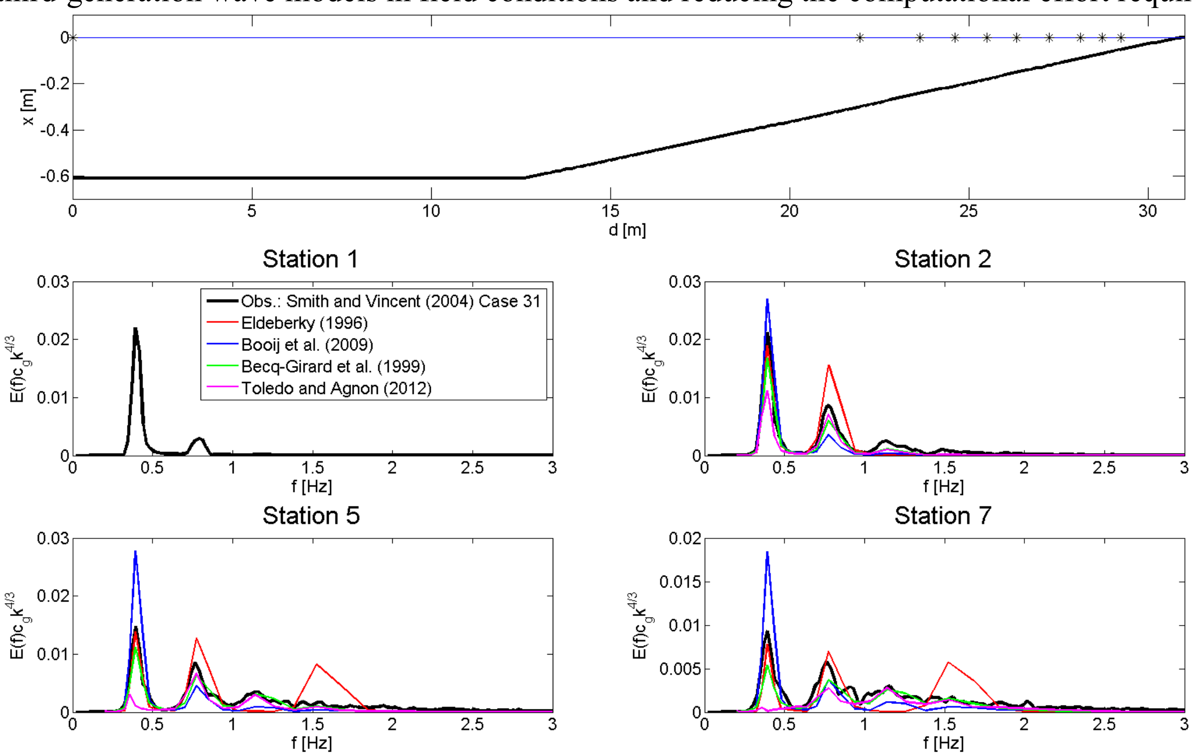

Figure 5. The evolution of the spectrum (stations 1, 2, 5 and 7 in the upper panel), computed with the LTA (Eldeberky, 1996), $DCTA_E$ (Booij et al., 2009) and SPB[2] (Becq-Girard et al., 1999) and *Toledo and Agnon* [2012]triad source terms over a 1:30 flat bed, compared with the spectra

observed by *Smith* [2004]. Note that the vertical scale is such that a $k^{-4/3}$-tail would appear as a horizontal line.

Long wave generation in the coastal zone

The SWASH model has been applied to simulate long-wave generation at the FRF, Duck, NC. The computational results were compared with observations and show reasonably agreement with measured data. The experiement were executed with one layer in the SWASH model. We are now investigating the influence of additional layers in the vertical on the prediction of long waves in the coastal zone. The computations were executed at Imperial College London, in close collaboration with Shell and Delft University of Technology.

RESULTS

The collection of shallow water wave flume data has been extended and rearranged with additional data for the verification of new parameterisations of shallow water processes.

A new parameterisation for wave breaking in shallow water over sloping and flat bottoms was reformulated, including a dependence on directional spreading and implemented in the SWAN model.

A new parameterisation for triad interactions in shallow is being developed. As a first step, some inconsistencies in the LTA formulation were removed. In a second step the method of Beck (1999) has been implemented and promising results were obtained.

The SWASH model has succesfully been applied to predict the generation of long waves in the coastal zone.

IMPACT/APPLICATIONS

Economic Development
The improvements to coastal wave prediction models as developed in this project, will contribute to various economic activities on the continental shelf and the coastal zone, such as fisheries, shipping harbor development and offshore industry. Further, the availability of improved nearshore wave prediction models will benefit coastal and ocean engineering companies e.g. in the design and operation of offshore and coastal structures, and the development of coastal management strategies.

Quality of life
The improvements to coastal wave prediction models as developed in this project, will improve modeling capability of coastal circulation, morphological development, surge prediction and transport processes, which will benefit coastal recreation (more reliable knowledge of wave heights, rip currents etc), coastal management, and help mitigate pollution hazards for humans (recreation) and coastal ecosystems.

TRANSITIONS

Economic Development
The developments in this project will be made available as open source software and as modules to widely used operational wave models. These models are used by NOAA/NCEP and other agencies involved in coastal development and management, and by many coastal and ocean engineering companies.

Quality of life
The software developed within this project will be disseminated in open source models used by local and federal agencies and companies involved in coastal recreation (surf prediction, rip currents, pollution, surge prediction), coastal management, and mitigation of coastal hazards.

RELATED PROJECTS

Coastal Wave Observations at FRF, Kitty Hawk, NC, USA. This project is carried out by Jeff Hanson, Kent, Hathaway and Harry Friebel. It is strongly related to our project for exchange of field data.

Modeling Wind Wave Evolution from Deep to Shallow Water; Nonlineary and Dissipation. Grant N0014-10-1-0453. PI's: Tim Janssen (San Francisco State University), Tom Herbers (Naval Postgraduate School) and Gerbrant van Vledder (Delft University of Technology).

SWAN and SWASH development teams, Delft University of Technology, Delft, The Netherlands. http://www.swan.tudelft.nl & http://swash.sourceforge.net.

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